

THE EFFECTS OF GRASS AND RAINFALL PATTERN ON THE MATRIC
SUCTION OF ACIDIC SOIL SLOPES

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ABSTRACT

Among the mechanism that leads to slope failures are that the matric suction starts to decrease when water infiltrates the soil. Although many studies have been carried out to improve stability of slope, most studies often ignore the influence of matric suction induced by vegetation. Grass can be classified into many different types and appearances. For this research, Bermuda grass and Signal grass were used to investigate matric suction due to rainfall by applying hydromulching on sloping ground. Despite numerous efforts in the past to investigate the influence of rainfall infiltration on slope stability, there was limited research on the effect of both rainfall infiltration and evaporation on sloping ground. This study provides an insight on how matric suction changes after applying hydromulching on the sloping ground of acidic soil slopes. A large-scale model (with four slope surfaces) and rainfall simulator were used to measure the matric suction of soil at a depth of 20 cm by a soil moisture sensor. This research investigate the variations in matric suction profiles under a loose and compact soil condition, treated and untreated dolomite, bare plot and a grassed surface in acidic soil slopes response to rainfalls pattern. The field monitoring results showed the ability of both (Signal & Bermuda) grass covers to maintain the matric suction on acidic soil slopes during rainfall. The rate of changes in suction for bare slope surface is much faster as compared to grass-covered slope surface. The finding showed the hydromulching creates grass cover on top of acidic soil slopes and the grass influence the matric suction. The thesis has contributed to some original outcomes. First, how distribution of matric suction changes in sloping ground after apply hydromulching. Second, implementation of an easy and effective matric suction measurement method by using sensors in field work. Last, the results of the study proved that the hydromulching method with additives such as dolomite, fertilisers can be used for this acidic soil.

ABSTRAK

Antara mekanisma yang membawa kepada kegagalan cerun adalah sedutan matrik mula berkurang apabila air menyusup dalam tanah. Walaupun banyak kajian telah dijalankan untuk meningkatkan kestabilan cerun, kebanyakan kajian sering mengabaikan pengaruh sedutan matriks yang disebabkan oleh tumbuh-tumbuhan. Rumput boleh diklasifikasikan dalam pelbagai jenis dan rupa. Untuk kajian ini, *Bermuda grass* dan *Signal grass* digunakan untuk menyiasat sedutan matriks disebabkan oleh hujan dengan menggunakan *hydromulching* di tanah cerun. Walaupun telah banyak usaha untuk menyiasat pengaruh infiltrasi hujan pada kestabilan cerun, terdapat kajian terhad mengenai kesan kedua-dua penyusupan dan penyejatan hujan di tanah cerun. Kajian ini memberi pemahaman tentang bagaimana perubahan sedutan matriks selepas penggunaan *hydromulching* di permukaan cerun tanah berasid. Model berskala besar (dengan empat permukaan cerun) dan simulasi hujan digunakan untuk mengukur sedutan matriks pada kedalaman 20 cm dengan penyesan kelembapan tanah. Kajian ini menyiasat variasi profil sedutan matrik di bawah tanah yang longgar dan padat, dolomit yang dirawat dan tidak dirawat, plot terdedah dan permukaan berumput di kawasan tanah cerun berasid yang bertindakbalas terhadap corak hujan. Hasil pemantauan lapangan menunjukkan keupayaan kedua-dua rumput dapat mengekalkan sedutan matriks pada cerun tanah berasid semasa hujan. Kadar perubahan sedutan matrik pada permukaan terdedah lebih cepat berbanding dengan permukaan cerun yang dilindungi. Temuan menunjukkan *hydromulching* memberi penutup rumput di atas tanah cerun berasid dan rumput mempengaruhi sedutan matriks. Tesis ini telah menyumbang kepada beberapa hasil. Pertama, bagaimana pengedaran perubahan sedutan matrik dalam cerun tanah selepas penggunaan *hydromulching*. Kedua, pelaksanaan kaedah pengukuran yang mudah dan berkesan dengan menggunakan alat penyesan di kerja lapangan. Akhirnya, hasil kajian membuktikan bahawa kaedah *hydromulching* dengan tambahan seperti dolomit dan baja boleh digunakan untuk tanah berasid ini.

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LIST OF SYMBOLS AND ABBREVIATIONS

h	-	Soil suction or total suction
R	-	Universal gas constant
T	-	Absolute temperature
v_{wo}	-	Specific volume of water or the inverse of the density of water
ω_v	-	Molecular mass of water vapor
u_v	-	Partial pressure of pore water vapor
u_{vo}	-	Saturation pressure of water vapor over a flat surface of pure water at the same temperature
π	-	Osmotic suction
M_c	-	Moisture content (%)
LL	-	Liquid Limit
PL	-	Plastic Limit
PI	-	Plasticity Index
c'	-	Effective cohesion
ϕ'	-	Angle of internal friction associated with the net normal stress ($\sigma' - u_a$)
ϕ_b	-	Angle indicating the rate of increase in shear strength relative to matric suction, $(u_a - u_w)$.
k_w	-	Coefficient of permeability with respect to the water phase

∂_{hw}/∂_y - Hydraulic head gradient in the y-direction

h_w - Hydraulic head (the sum of the elevation and pore-water pressure heads)

x and y - Cartesian coordinates in the x- and y-direction

ρ_w - Density of water

g - Gravitational acceleration

m_2^w - Coefficient of water volume change with respect to a change in matric suction or the slope of the SWCC.

β - Sloping distance across the base of a slice

R - Radius for a circular slip surface or the moment arm associated with the mobilised shear force on the base of each slice

N - Total normal force on the base of the slice

W - Total weight of a slice of width b and height h

x - Horizontal distance from the centreline of each slice to the centre of rotation or to the centre of the moments

f - Perpendicular offset of the normal force from the centre of rotation or from the centre of moments

α - Angle between the tangent to the centre of the base of each slice and the horizontal

m_1 - Mass of the pycnometer bottle (g)

m_2 - Mass of pycnometer bottle and dry soil (g)

m_3 - Mass of pycnometer bottle, soil and water (g)

- m_4 - Mass of pycnometer bottle when full of water only (g)
- a - Area of cross-section of standpipe tube
- A - Area of cross section of sample
- h_1 - Heights of water above datum in standpipe at time t_1
- h_2 - Heights of water above datum in standpipe at time t_2
- L - Heights of sample
- t - Elapsed time (minutes)
- m_s - Mass of core cutter and wet soil
- m_c - Mass of core cutter
- V_c - Volume of core cutter
- w - Moisture content
- \bar{i} - Average rainfall intensity
- Q - Sprayed discharge
- σ - Standard deviation
- CU - Uniformity coefficient
- CV - Coefficient of variation of the rainfall intensity

CHAPTER 1

INTRODUCTION

1.1 Background of study

In tropical regions which experienced period of intense or prolonged rainfall events, heavy rainfalls along with hot temperature and other humid climatic conditions result in the formation of deep residual soil profile. This residual soil commonly exists in unsaturated conditions, with presence of negative pore-water pressure or matric suction. The negative pore-water pressure contributes additional shear strength to the unsaturated residual soil. This additional shear strength normally ceases or reduces considerably enough to trigger slope failure due to loss of matric suction as wetting front progresses from the ground surface (Fredlund & Rahardjo, 1993; Rahardjo *et al.*, 2005; Fredlund, Rahardjo & Fredlund, 2012). A rainfall infiltration process in unsaturated soils is a complex process which heavily affects slope stability conditions (Cuomo & Della Sala, 2013). The failure mechanisms are mainly due to the loss of matric suction of soils by rainwater. When rainwater infiltrates into the slopes, it is known that it will start to saturate the soil hence, reduce the matric suction.

The effect of negative pore-water pressure is often ignored in slope ground studies. There is a perception among geotechnical engineers that negative pore-water pressures will dissipate with rainfall infiltration and cannot be relied upon in design considerations (Zhang *et al.*, 2004). The wetting front of rainwater will continue to move into the soil even after the rain has stopped. Due to rainfall, different types of slope instability phenomena (either slope failures or erosion-like phenomena) are triggered which cause, in turn, different flow-like mass movements (Cascini *et al.*, 2014). Movement of the wetting front stops when an equilibrium or steady state

condition is achieved. Basically, it is known that infiltration impairs slope ground. However, since it is often not measured off directly from the field, its assessment often relies on the vague correlation with rainfall and runoff. The correlation between rainfall and sloping ground involves a large number of factors (Huat, Ali & Low, 2006). Some of these factors such as rainfall duration and intensity, slope surface cover, degree of saturation, slope angle, permeability ratios and perched water table are extremely difficult to evaluate.

Unsaturated soil mechanics is often applied to geotechnical problems such as embankments, dams, pavements, foundations, landfills, slopes and nuclear waste disposals. Analyzing such problems requires information about soil suction variations. This explains why the significant effort has been made from all over the world on suction measurement techniques under field conditions. Unsaturated soil mechanics have been studied intensively in recent years. The behaviour of unsaturated soil in the field is extremely delicate to the flex changes of groundwater table and rainfall infiltration (Wu & Selvadurai, 2016). A better understanding of soil mechanics would mean a better design of slopes in terms of cost and safety. There are different ways of approaching the unsaturated zone, but Lu and Likos (2004) suggest that it can be pictured as two different zones: a seasonal steady zone and a seasonal unsteady zone. In the unsteady zone near the surface, various time-dependent factors as relative humidity, temperature, precipitation and evaporation among others cause the soil suction to fluctuate. The steady zone is situated below this zone and is relatively time independent. Properties such as the steady recharge rate, surface topography, soil type and the groundwater table strongly influence the suction profile in this zone.

Natural soils in an unsaturated state are common in arid or semi-arid areas where the groundwater table is often many meters deep. Around one-third of the earth's surface is situated in arid or semi-arid regions where the potential evaporation exceeds the precipitation (Alonso & Delage, 1995). However, any soil near the ground surface in a relatively dry environment is liable to have a negative pore water pressure (water pressure relative to a datum of atmospheric air pressure) and could experience desaturation or air entry into the pore spaces. Though the soil may be saturated for a certain height above the water table, air will enter pore spaces if the pore water pressure drops sufficiently (Vanapalli & Oh, 2012). Figure 1.1 illustrates the change from a

positive pore water pressure below the water table to a negative pore water pressure above the water table. While the plot indicates a reduction in negative pore water pressure close to the ground surface where precipitation would increase the degree of saturation, increased desiccation due to evaporation can be expected to occur in a hot environment (Bell, Cripps & Culshaw, 1986). Negative pore water pressure is the key to understanding unsaturated soil behaviour.

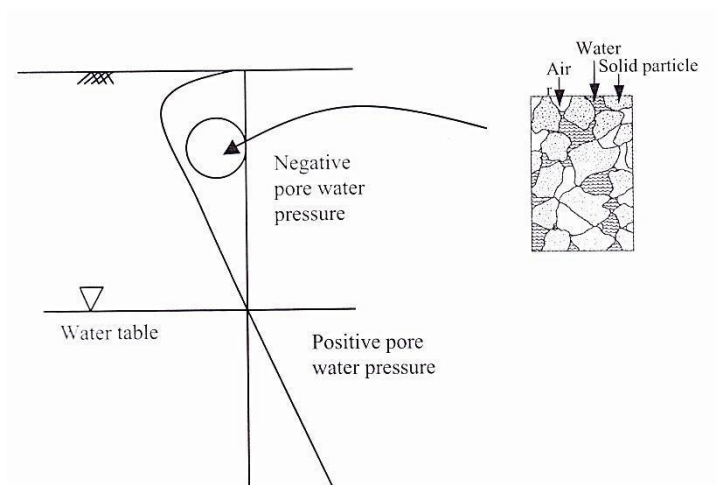


Figure 1.1: Unsaturated soils in the ground (Vanapalli & Oh, 2012)

Climate plays an important role in the formation of unsaturated soil (Ng & Menzies, 2007). Evaporation during hot weather can cause the ground to dry out, leading to the shrinkage of fine-grained soils which ultimately results in shrinkage cracking. Subsequent wetting, following rain, leads to the swelling and closure of cracks. However, this does not necessarily eradicate suction induced soil structure. Future climate changes due to global warming could potentially cause significant changes to the soil moisture regime and soil conditions in large areas. The uptake of water by vegetation can also lead to significant ground de-saturation due to evapotranspiration while the removal of vegetation can lead to subsequent re-saturation which causes potential stability problems.

The erosion of residual or acidic soil slopes has become a serious problem (Saifuddin & Normaniza, 2016; Jing *et al.*, 2019). Furthermore, some of the areas are highly acidic as the soil has a low pH. In fact, residual acidic soil slopes which are not covered by vegetation greatly increase soil erosion rates (Osman, Saifuddin & Halim, 2014). Slope failures or soil erosion could cause damage to human lives as well as

property. This is because acidic soil slope areas are not able to support the development and growth of any vegetation. According to Craswell & Pushparajah (1989), acidic land covers expansive areas in southern China, Thailand, Laos, Vietnam and even Malaysia, particularly on the upper slopes of hillsides. The formation process of residual soil is strongly influenced by climate, rainfall, tides and landforms.

The application of crop residue mulches can contribute to improve the soil fertility and soil properties that affect crop productivity (Jordán, Zavala & Gil, 2010; Mulumba & Lal, 2008). The mulching of agricultural lands increases the content of soil organic matter (Saroa & Lal, 2003) that helps to improve soil aggregation (Mulumba & Lal, 2008), and hence positively affects soil porosity, which improves water infiltration, reduces runoff and controls soil erosion (Edwards *et al.*, 2000; Jordán *et al.*, 2010; Mulumba & Lal, 2008; Rees *et al.*, 2002;). Hydromulches, such as those made from wood products combined with water, are a surface cover commonly applied in both urban settings and disturbed soils to reduce erosion and provide grass seed (hydroseeding; Megahan, Wilson & Monsen, 2001; Prats *et al.*, 2016). Although hydromulches have been studied extensively as a way to reestablish vegetation communities, their impact on the moderation of rainfall and matric suction has not been described. The effects of mulching on soil moisture depend on precipitation and climatic factors. Mulching favorably influences soil moisture regime by controlling surface evaporation rate; in summer, mulching conserves soil moisture by reducing the evaporation rate. Mulches improve soil-moisture retention capacity as well as soil structure and suppress weed growth (Mutetwa & Mtaita, 2014). The amount of soil-moisture conservation under different mulching materials differs in different soil types and climatic conditions. In general, the mulching treatments store higher soil moisture compared to the bare soil (no mulch) (Chakraborty *et al.*, 2008; Zhao *et al.*, 2014).

In general, the main causes of landslides in most unsaturated slopes are often initiated by the process of infiltration or rising pore water pressures (Schnellmann *et al.*, 2010; Lourenc, Wang & Kamai, 2015). These unsaturated slopes have soils that have different water contents from the ground surface (dry condition) to a considerable depth (saturated), and the pore water pressure in this unsaturated zone is generally negative with respect to atmospheric pressure. The presence and magnitude of suction pressure have been found to be important to the stability of such kind of slopes

(Sorbino & Nicotera, 2013). Infiltration of rainfall leads to a reduction in soil matric suction, or the rising of the water table results in an increase in pore water pressure (from negative to positive at the potential shear surface). This, in turn, results in a decrease in shear resistance on the potential failure surface to a point where equilibrium can no longer be sustained in the slope and then failures can occur (Fredlund & Rahardjo, 1993). Therefore, studies of SWCCs can assist in the understanding of pore water pressure distributions in the slope.

1.2 Problem statement

It has been established that rainfall infiltration trigger slope failures by inducing the increase in moisture content and reducing or eliminating matric suctions. However, the distribution of matric suction is also known to be influenced by evaporation process. Despite of many works done on the influence of rainfall infiltration on slope stability, not much effort have been given to combine the effect of rainfall infiltration and evaporation on the sloping ground. The difference between the downward flux (precipitation) and the upward flux (evaporation and transpiration) is thought to have influence on the suction distribution in soil especially near ground surface. This study gave insight on how matric suction changes on sloping ground after apply hydromulching. Furthermore, soil acidity will directly affect plant growth. Raindrops falling on a bare soil break down the structure of the surface soil and detach particles. If the land is sloping and the water cannot be immediately absorbed by the soil, the water moves off down the slope in the form of run-off, carrying dislodged particles with it. To minimize this problem, remediation using hydromulching method of acidic soil need to be done whether it successful or not. There is no information available on the effect hydromulching of the matric suction on acidic soil slopes. Therefore there was a need to investigate the changes matric suction on bare slope and grass slopes. Most of the slope failures in unsaturated tropical residual soil in Malaysia are mainly due to infiltration, especially during intense and prolonged rainfall which reduces the soil matric suction. The implementation of unsaturated soil mechanics in the field of engineering is hampered by the lack of field data. Therefore, there is a need to assess the capability of other models and approaches.

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